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A vertically-polarized transmitting aerial for u.h.f. relay stations

RESEARCH REPORT No. E-122

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THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

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RESEARCH DEPARTMENT

A VERTICALLY-POLARIZED TRANSMITTING AERIAL FOR U.H.F. RELAY STATIONS

Research Report No. E-122
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A VERTICALLY-POLARIZED TRANSMITTING AERIAL FOR U.H.F. RELAY STATIONS

SUMMARY

The design of an aerial is described which is suitable for use at the majority of relay stations and is relatively cheap to manufacture and easy to install.

1. INTRODUCTION

In 1963 the BBC invited tenders from a number of commercial firms for the construction of complete u.h.f. relay stations. The offers received for the transmitting aerials were all based on the use of aerial panels similar to those in use for main stations; they were costly and imposed a high wind load on the support mast and were therefore considered unacceptable. In consequence, the BBC decided, early in 1964, to undertake the design and manufacture of aerials for the first four relay stations; the design was also to be made available to firms contracting for the supply of aerials for later stations.

The foreseeable demand for these aerials was considerable: it was expected that about 40 would be required for relay stations of Types 1 and 2 (effective radiated powers 2-10 kW) in the service areas of the first ten main stations, with a further 90 aerials for the next 37 main stations. It was therefore imperative to strive for a design which was relatively cheap to manufacture and easy to install. It was also desirable to minimise, as far as possible, the number of different types of aerials, i.e. to make each aerial cover as many different channels as possible, preferably without adjustment, and to restrict the choice of radiation patterns.

2. GENERAL REQUIREMENTS

2.1. H.R.P. requirements.

Instead of considering the h.r.p. requirements of each station in isolation, an attempt was made to find a simple aerial whose h.r.p. would have widespread application. Three possible aerials were considered:

(a) a dipole spaced one quarter-wavelength from a slender conducting pole giving a cardioidal shape of h.r.p.

(b) a dipole spaced one half-wavelength from a slender conducting pole giving an elongated h.r.p. and

(c) an unspecified arrangement giving an omnidirectional h.r.p.

An assessment was then made* of the requirements for the first 40 relay stations, using such site information as was available at the time, in order to determine which type of h.r.p. was preferred. It was found that the cardioid h.r.p. had the most widespread application, being the first choice at 42%, and adjudged acceptable at 70%, of the sites considered. Accordingly, the initial development was concentrated on this type of aerial.

2.2. V.R.P. requirements

The aerial v.r.p. was required to be gapfilled in accordance with the specification used for the main station aerials, namely that the field should not fall below the following values:-

$\frac{E}{2\pi A}$ cosec $(\theta - \theta_T)$ for θ between the half amplitude point of the main lobe and 15°.

and

$\frac{E}{4\pi A}$ cosec $(\theta - \theta_T)$ for greater angles up to 25°

where:

θ is the angle measured below the horizontal.

---

* By Mr. R.S. Sandell.

θ_r is the angle of beam tilt.

A is the aperture of the aerial in wavelengths.

E is the maximum amplitude of the v.r.p. on the bearing concerned.

The main lobe of the v.r.p. was required to be tilted downwards. The ideal angle of tilt would vary from site to site but for the majority of sites was expected to lie in the range of 1° - 2° and was not expected to be critical for an aerial radiating length of the order of 16 wavelengths.

2.3. Gain requirements

The transmitting aerial gains required for the larger types of relay station are summarized in the following table.

TABLE I

Relay type	Maximum e.r.p.	Translator power	Required maximum aerial gain
1	10 kW	1 kW	10 dB
2	2 kW	0·2 kW	10 dB
3	0·5 kW	0·05 kW	10 dB
4	0·1 kW	0·05 kW	3 dB

Thus one aerial design, if reasonably simple and cheap, could satisfy the requirements of the first three types of relay stations.

The aerial gains given in Table 1 are effective gains, so that the required intrinsic gain is higher in order to offset losses in the feeders etc. Thus the radiating length required was in the range 16λ - 20λ, depending on the magnitude of losses and the shape of the h.r.p.

2.4. Bandwidth

Each aerial was required to be suitable for operation, without adjustment, on at least four channels in a standard group. Moreover, if one aerial could be used for more than one standard channel group, the number of different versions required would be reduced. The allocations of the channels at the majority of stations fall into three standard groups as shown in Figure 1. If the additional non-standard channels (i.e. 30, 34, 48, 52, 56, 66, 67, 68) are added, the bandwidths of the groups are as follows:-

Channels 21 - 34	1·239 : 1	(±10·6%)
Channels 39 - 52	1·182 : 1	(± 8·4%)
Channels 53 - 68	1·176 : 1	(± 8·1%)

These bandwidths are within the capabilities of an aerial of conventional design, provided reasonable care is exercised. The possibility of making one aerial to cover channels 39 - 68 (bandwidth 1·391 : 1) was considered but a successful result was insufficiently assured, at least for Type 1 stations.

2.5. Impedance

The normal impedance specification[1] requires that aerial reflections radiated with a delay of 0·6 μs or greater should have a relative amplitude not greater than -38 dB. At the majority of installations, using a 45·7 m (150 ft.) support tower, the delay will be only about 0·5 μ sec. so that a 2 dB

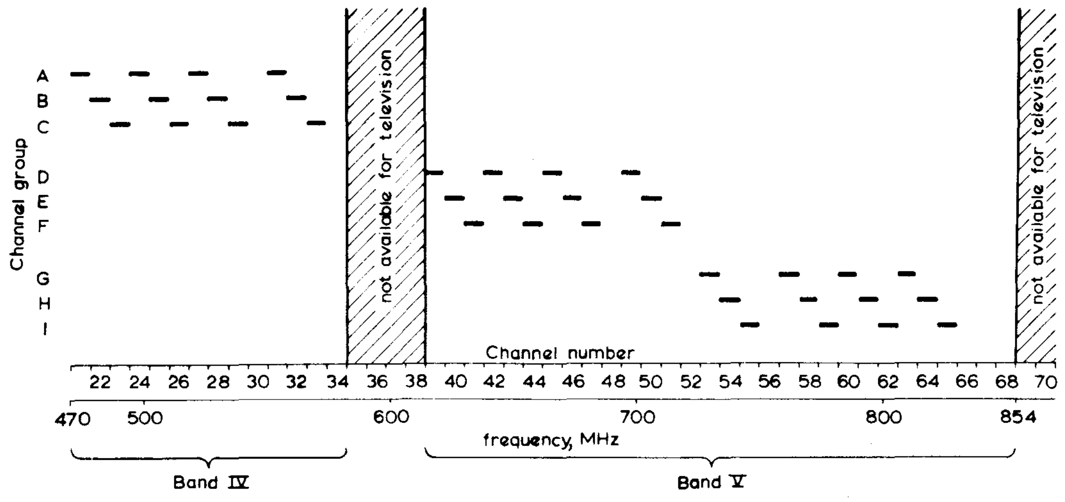

Fig. 1 - Distribution of standard channel allocations.

relaxation in the specification is permissible[1]. The corresponding aerial reflexion coefficient for a Type 1 station using a klystron amplifier is deduced in Table II.

TABLE II

Required relative level of radiated delayed signal	−36·0 dB
Attenuation resulting from two traversals of:	
Feeder ground run	+ 0·4 dB
Combining network	+ 2·0 dB
Reflexion loss at klystron	+ 2·0 dB
Permissible reflexion coefficient at input to diplexer	− 31·6 dB
i.e.	2·6 %

Since the combining network may not be installed until after a period of operation on a single channel, it is desirable that the aerial reflexion coefficient be 2 dB less than that given above, i.e. 2·1%.

At lower-power stations using travelling-wave-tube amplifiers, the reflexion loss at the amplifier will be about 15 dB*, so that the aerial reflexion coefficient may be 13 dB higher than the above figures, namely 11·6% and 9·4% for final and initial operation respectively.

2.6. Cross-polarization

In order to give the greatest possible protection to main stations using the same channels, it was required that any component of horizontally-polarized field in any direction of azimuth and over the arc ± 3° in elevation should not exceed −20 dB relative to the maximum value of the vertically-polarized component.

2.7. Maintenance

Requirements for maintenance can have considerable influence on the physical form of an aerial and therefore on its electrical performance. Thus if it is desired to have a screened shaft passing through the aerial, so that it may be climbed when on power, the minimum cross-sectional dimensions are determined by the climbing space. In view of the large number of relay stations, the policy on maintenance facilities was examined to see whether any worthwhile simplification of the aerial could be achieved. In consequence, it was decided to abandon the climbing requirement and to accept that normal maintenance would be done out of programme hours. As the stations are to be unattended, it was thought that this would not lead to any appreciable increase in the duration of fault conditions.

3. DESCRIPTION OF AERIAL

The aerial is intended primarily for mounting as a topmast on a standard 45·7 m (150 ft.) high self-supporting tower as shown in Fig. 2, although other forms of mounting, e.g. on a building or water tower, can be employed when required. Mechanical strength

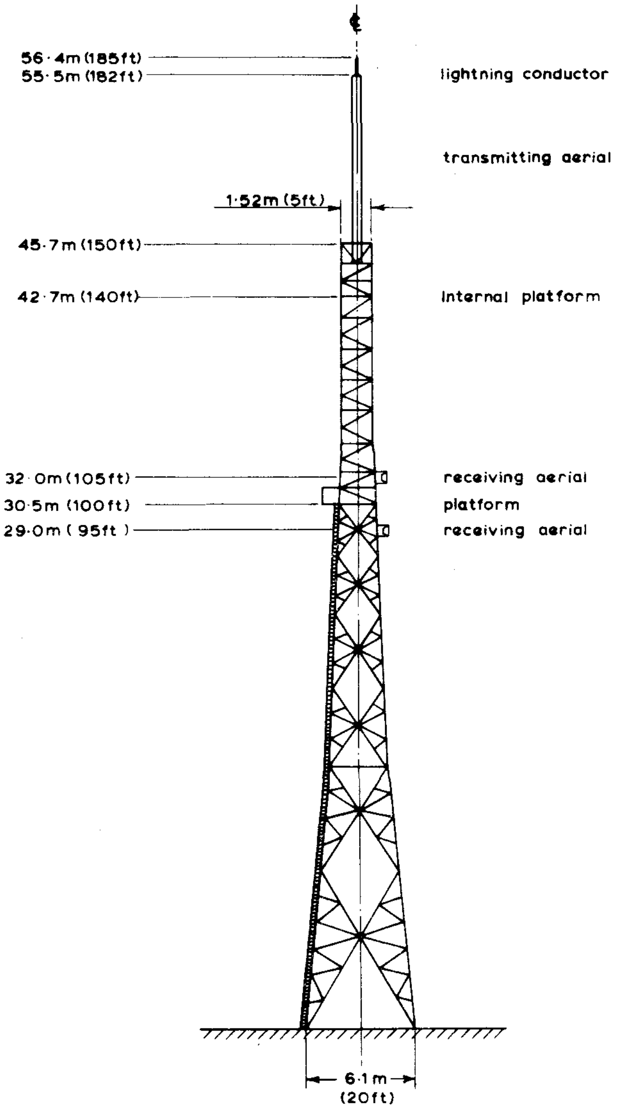

Fig. 2 - Arrangement of aerials on standard tower.

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* This figure is derived from measurements on a prototype amplifier and will need verification on service equipments.

and weather protection are provided by a glass-fibre cylinder having an internal diameter of 387 mm (15¼ in.) and a total length of 11·0 m (36 ft.), of which 9·7 m (32 ft.) project above the tower. The aerial is normally enclosed by this cylinder as shown in Fig. 3, but may be lowered out of it for maintenance. Fig. 4 shows a prototype aerial being inserted in a horizontal glass-fibre cylinder for test purposes.

The construction of the radiating elements is shown in Fig. 5. Each half-wave dipole is supported by a Pawsey stub on an aluminium alloy channel with overall dimensions of 76 x 38 mm (3 ins. x 1½ ins.). These dimensions, which are not critical, were chosen to give a compromise between h.r.p. requirements and ease of accommodating the distribution feeders.

Each element is fed by a 13 mm (½ inch) diameter flexible distribution feeder type UR67 (Z_0 = 50 ohms) which is tapped across the Pawsey stub at a predetermined point (Sec. 4.4.). All the distribution feeders are passed down the inside of the support channel to distribution transformers mounted at the base of the aerial. Eight distribution feeders are paralleled at each transformer, giving an impedance of 6·25 ohms; the transformation of this impedance back to 50 ohms is accomplished in three stages in order to give a large impedance bandwidth.

The halves of the aerial are fed in quadrature by separate main feeders (type Hackethal HF 1 5/8 ins.) from a hybrid unit near the single transmitter; the schematic arrangement is shown in Fig. 6. The hybrid unit serves to divide the transmitter powers equally between the half-aerials and gives an impedance advantage as discussed in Section 4.4. The construction of the hybrid is shown in Fig. 7. It consists of a single quarter-wave transformer compensated by a quarter-wave short-circuited line of the same characteristic impedance, which matches the transmitter to the two aerial feeders.

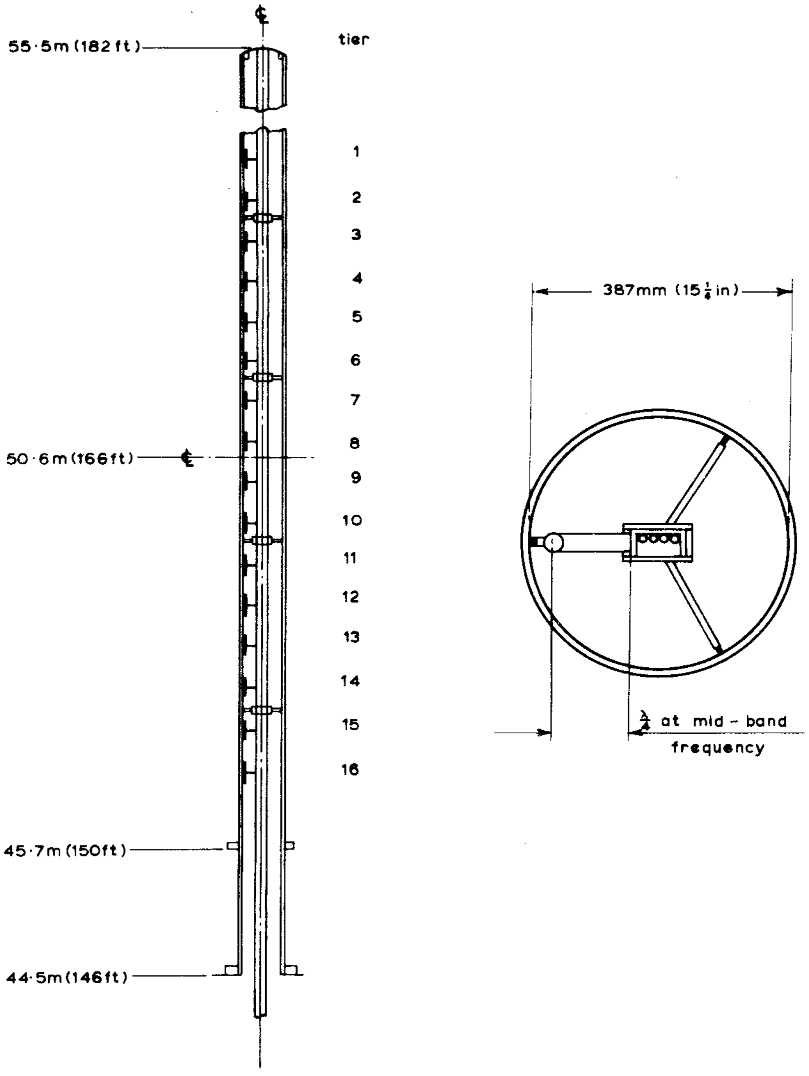

Fig. 3 - Arrangement of transmitting aerial in glass-fibre cylinder.

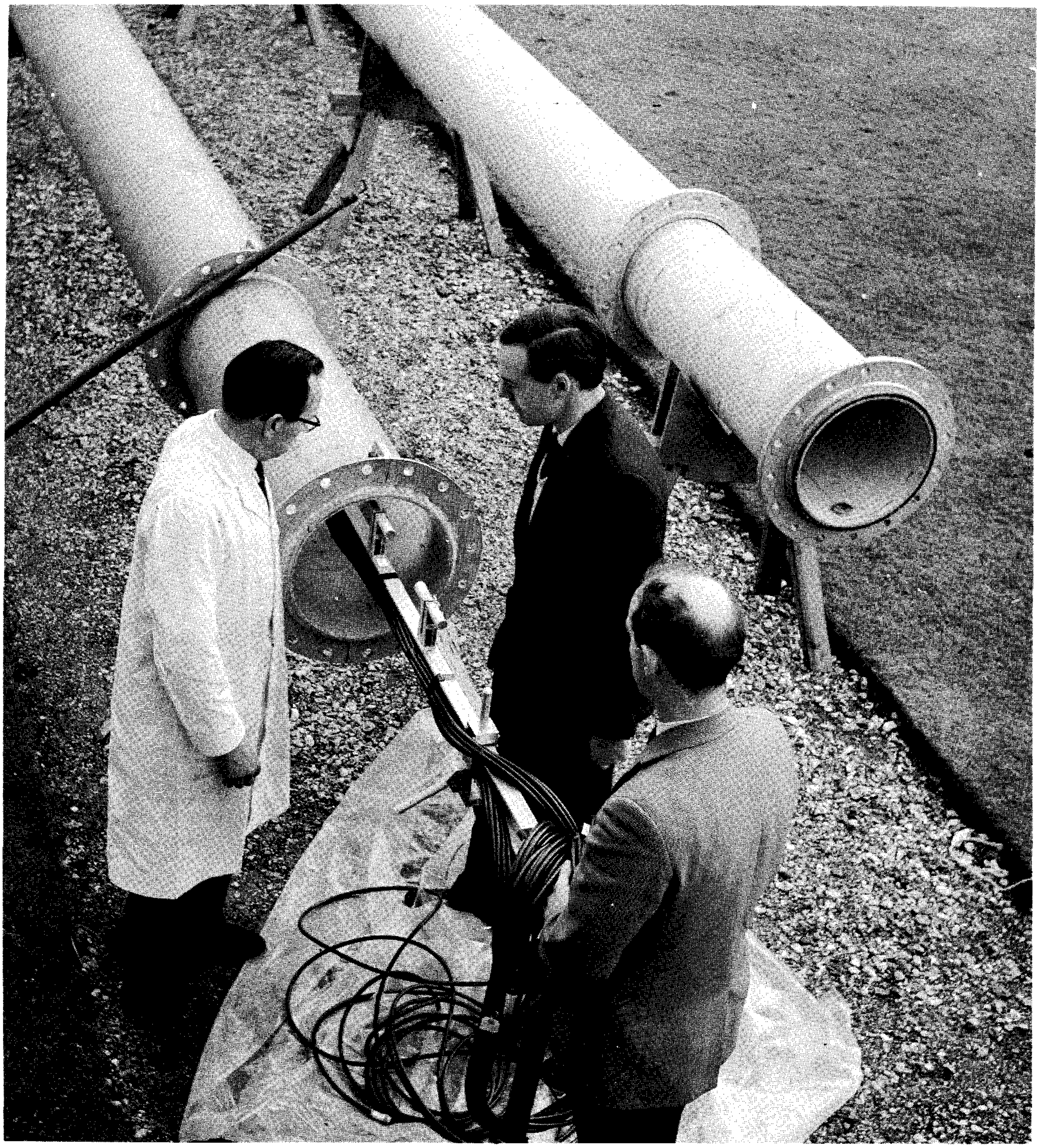

Fig. 4 - A prototype aerial being inserted in glass-fibre cylinder for impedance measurements.

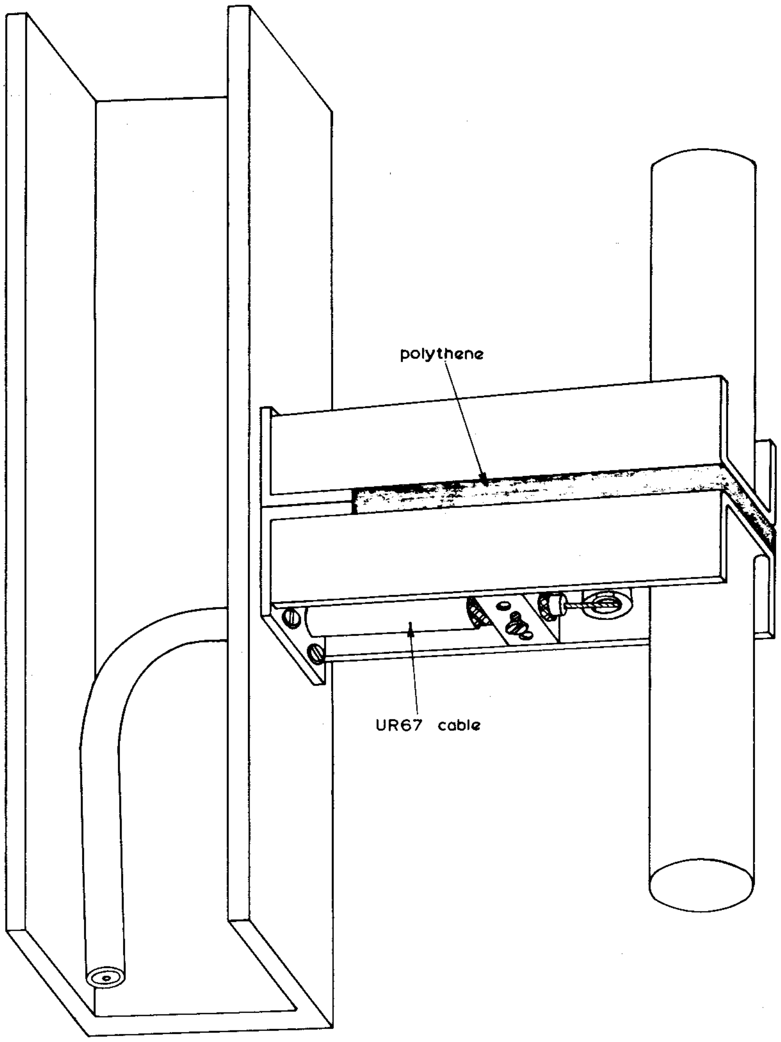

Fig. 5 - Construction of the radiating element.

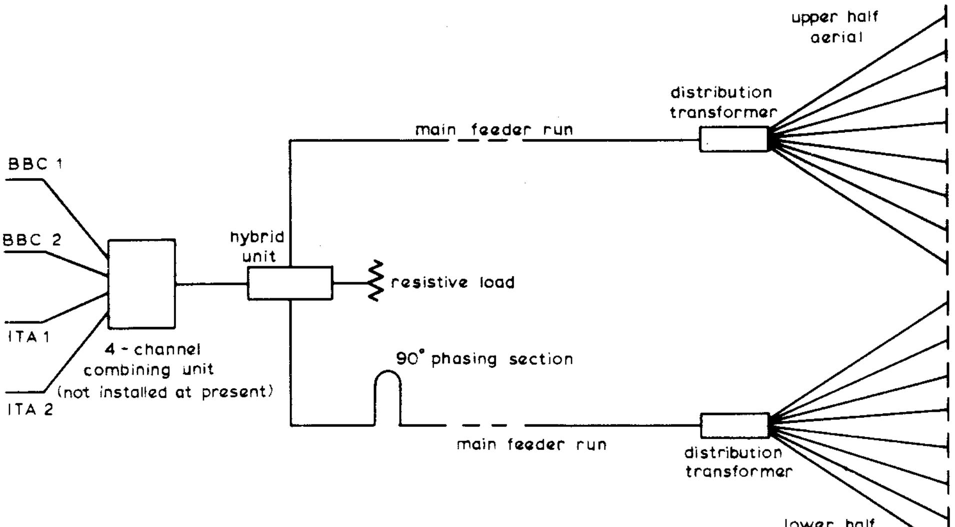

Fig. 6 - Schematic of feeding arrangement.

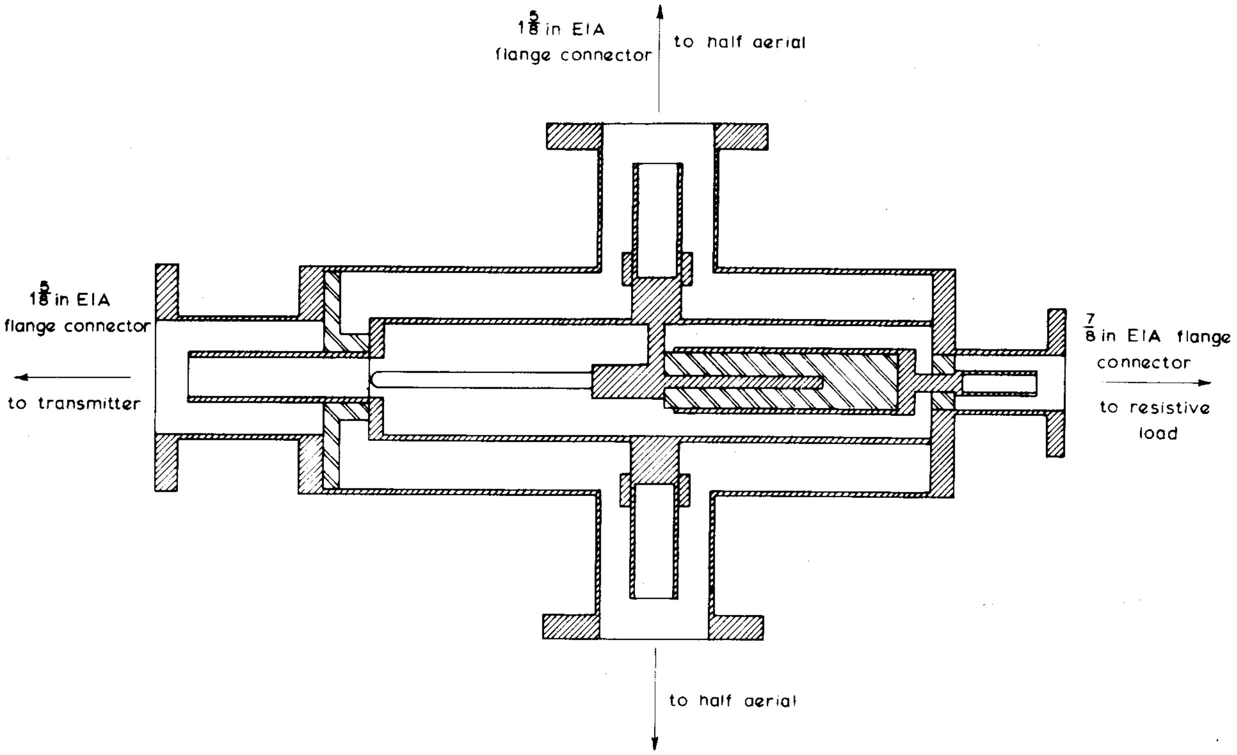
1 5/8 in EIA flange connector
to half aerial
1 5/8 in EIA flange connector
to transmitter
7/8 in EIA flange connector
to resistive load
to half aerial

Fig. 7 - Construction of split-drum hybrid.

The inner conductor of this line is divided longitudinally along its whole length; this does not affect the co-phased driving voltages to the half aerials but if the aerial reflexions are arranged to be in antiphase, they will appear as a voltage across the split in the inner conductor. The fourth pair of terminals on the hybrid is therefore connected across the split in the inner conductor by means of a transformer/balun arrangement.

4. PERFORMANCE

4.1. H.R.P.

H.R.P. measurements were made on one half of the aerial, which was erected complete in its glass-fibre cylinder. The h.r.p.s obtained in each of the three frequency bands are shown in Figs. 8 - 10; the extent to which the h.r.p. varies over each band is also shown.

4.2. V.R.P.

A theoretical study was made[2] of constant amplitude variable phase distributions which would satisfy the following requirements:

(a) meet the specification given in Section 2.2

(b) utilise a 90° phase difference between aerial halves

(c) give the greatest possible reduction of reflexions from the dipole elements when the half aerials were driven in quadrature from a power sharing network.

The distribution used is given in the second column of Table III. It was found that the distribution feeders could be cut fairly closely to these phases provided that all the feeder was taken from the same drum, but there appeared to be appreciable variations of velocity factor between drums. The most satisfactory technique was to cut each feeder a little oversize, to measure the electrical lengths and trim accordingly. Final measurements of the electrical length of the cables on one prototype aerial are shown in the fourth column of Table III. The estimated accuracy in both sets of measurements is ± 5° in phase and ± 5% in amplitude.

The v.r.p.s computed from the theoretical current distribution are shown in Fig. 11 for a range of frequencies.

The v.r.p. of the measured current distribution of Table III is given in Fig. 12.

4.3. Gain

The vertical spacing between dipoles was chosen to be one wavelength at mid-band frequency in order to maintain a reasonably constant gain over each frequency band. The variation of gain over a bandwidth of ± 10% is shown in Table IV.

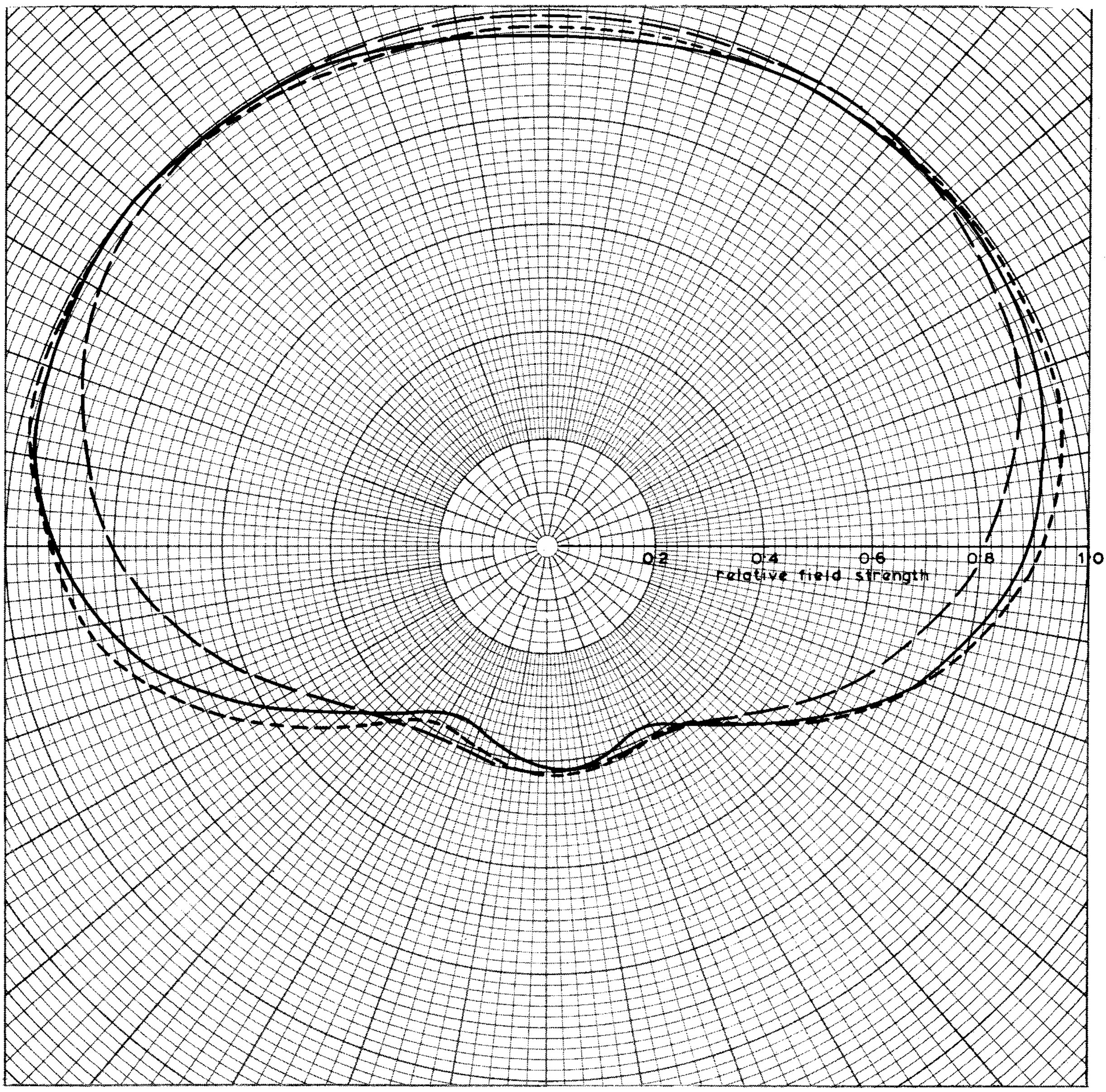

Fig. 8 - H.R.P. of Band IV aerial

— —	*470 MHz*	*Channel 21 Maximum/mean ratio 2·2 dB*
———	*540 MHz*	*Channel 29 Maximum/mean ratio 2·0 dB*
– – – –	*580 MHz*	*Channel 34 Maximum/mean ratio 1·8 dB*

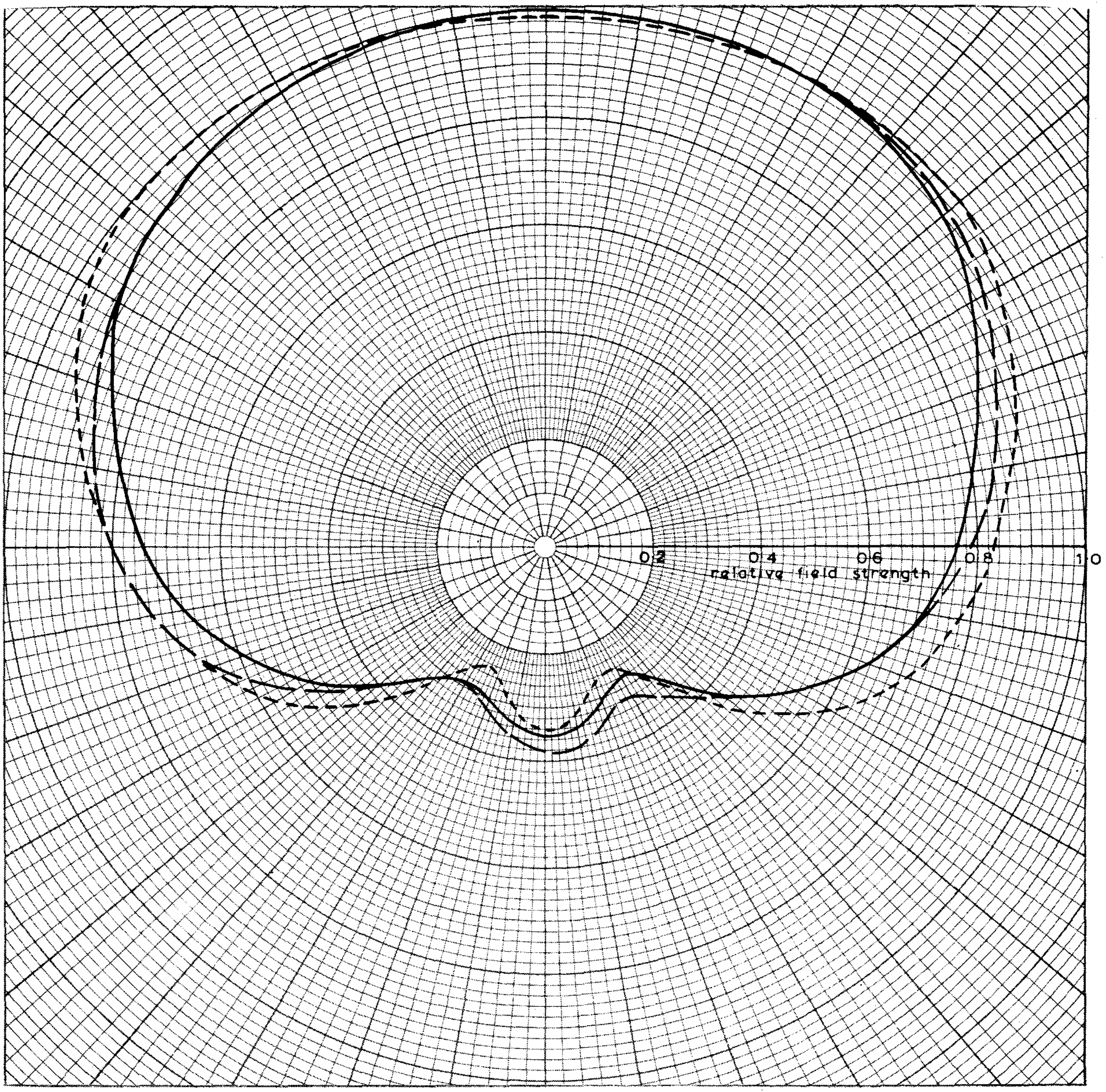

Fig. 9 - H.R.P. of lower Band V aerial

— — 615 MHz *Channel 39* *Maximum/mean ratio 2·4 dB*

——— 670 MHz *Channel 45/46* *Maximum/mean ratio 2·6 dB*

- - - - 725 MHz *Channel 52* *Maximum/mean ratio 2·2 dB*

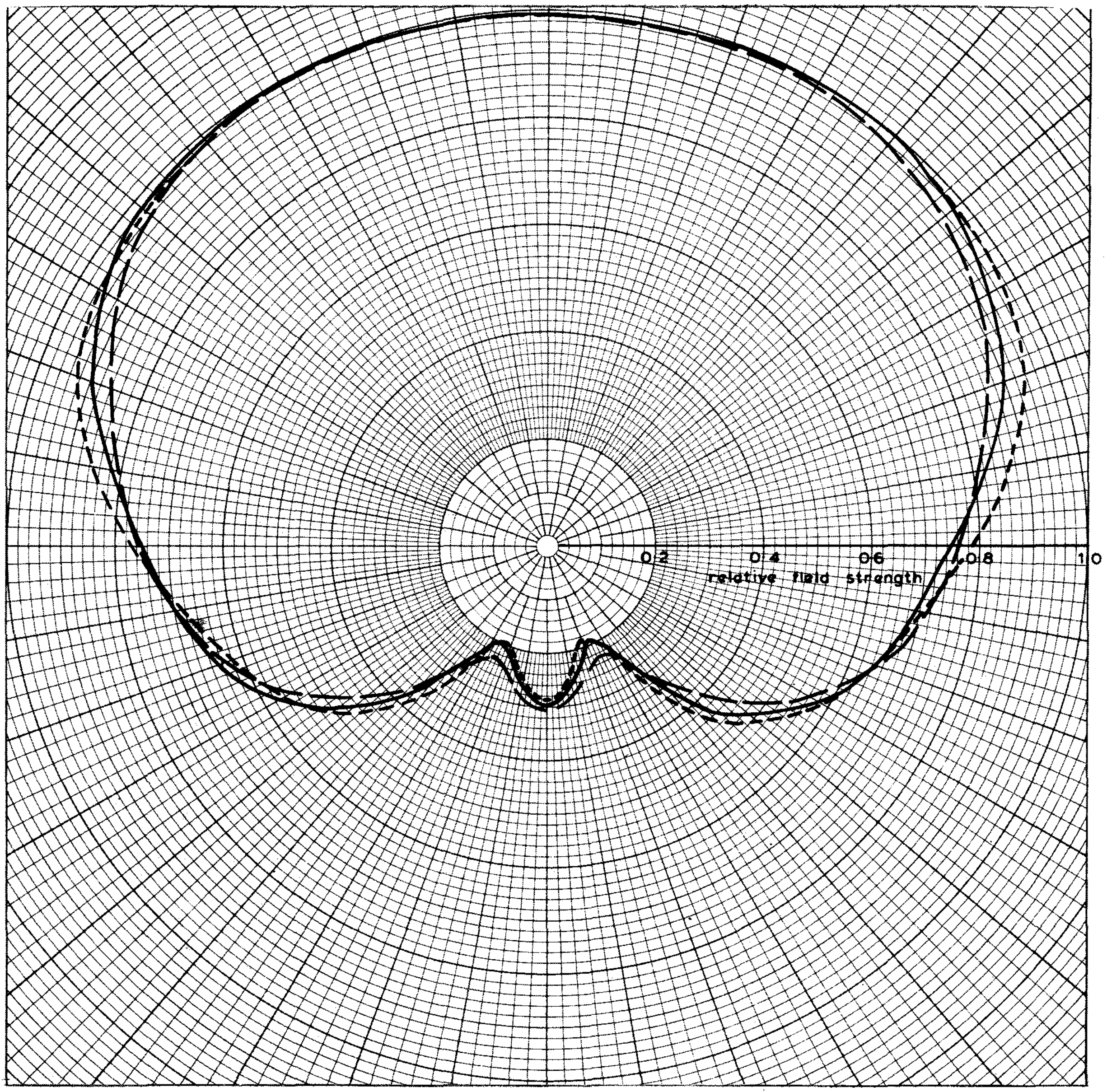

Fig. 10 - H.R.P. of upper Band V aerial

— — 730 MHz Channel 53 Maximum/mean ratio 2·6 dB
—— 790 MHz Channel 60/61 Maximum/mean ratio 2·5 dB
- - - - 850 MHz Channel 68 Maximum/mean ratio 2·4 dB

TABLE III

Vertical distribution of radiating currents Channels 39 - 52

Tier	Theoretical currents		Measured cable phases	Measured currents	
		ϕ	ϕ		ϕ
1 (top)	1·0	125°	123°	1·07	122°
2	1·0	120°	115°	1·00	127°
3	1·0	113°	115°	1·04	107°
4	1·0	116°	118°	1·06	115°
5	1·0	112°	113°	1·07	110°
6	1·0	116°	114°	0·99	115°
7	1·0	117°	110°	0·98	111°
8	1·0	141°	151°	1·09	152°
9	1·0	86°	93°	0·97	98°
10	1·0	52°	55°	0·98	54°
11	1·0	41°	44°	1·02	42°
12	1·0	27°	23°	0·98	22°
13	1·0	21°	13°	0·98	26°
14	1·0	8°	10°	1·00	6°
15	1·0	5°	9°	1·00	0°
16	1·0	0°	-3°	0·97	-3°

TABLE IV

Variation of gain over ± 10% bandwidth

Frequency	0·9 f_o	f_o	1·1 f_o
Mean intrinsic gain	12·4 dB	12·7 dB	12·4 dB
Gapfilling loss	0·5 dB	0·7 dB	0·8 dB
Net gain (excluding loss in distribution feeder)	11·9 dB	12·0 dB	11·6 dB

There is also some variation of maximum effective gain between the aerials for different channel groups, owing to different lengths of distribution feeder and changes in the h.r.p. Table V shows the calculations for the centre frequency of each channel group, assuming a standard installation on a 45·7 m (150 ft.) tower. When the installation is complete on four channels, there will be additional loss in the 4-channel combining unit. This loss is currently estimated to be 1·0 to 1·5 dB, so that the final effective gain will be about 10 dB as required.

4.4. Admittance

It was appreciated from the outset that particular attention to the matching of all parts of the aerial system would be required if the target bandwidth was to be met. Accordingly development started with the design of a wideband radiating element.

The initial design was for a full-wavelength dipole and a prototype was made which had an excellent bandwidth. However, the horizontal supports to the mid-point of each limb of the dipole carried a small current giving some radiation of the wrong polarization. The relative field in the wrong polarization was less than -20 dB over an arc of ±10° about the horizontal plane but rose to -10 dB at high angles in the vertical plane. The power lost in this mode was small and could have been tolerated; nevertheless it was thought undesirable to have any significant cross-polarized radiation and this form of element was abandoned in favour of a conventional half-wave dipole supported by a Pawsey stub. The admittance bandwidth of this element was slightly inferior to that of the full-wave dipole but was still sufficiently good.

The prototype elements were made with an adjustable feed point and Pawsey stub short-circuit in order to control the position of the characteristic on the Smith chart. Mutual admittances between

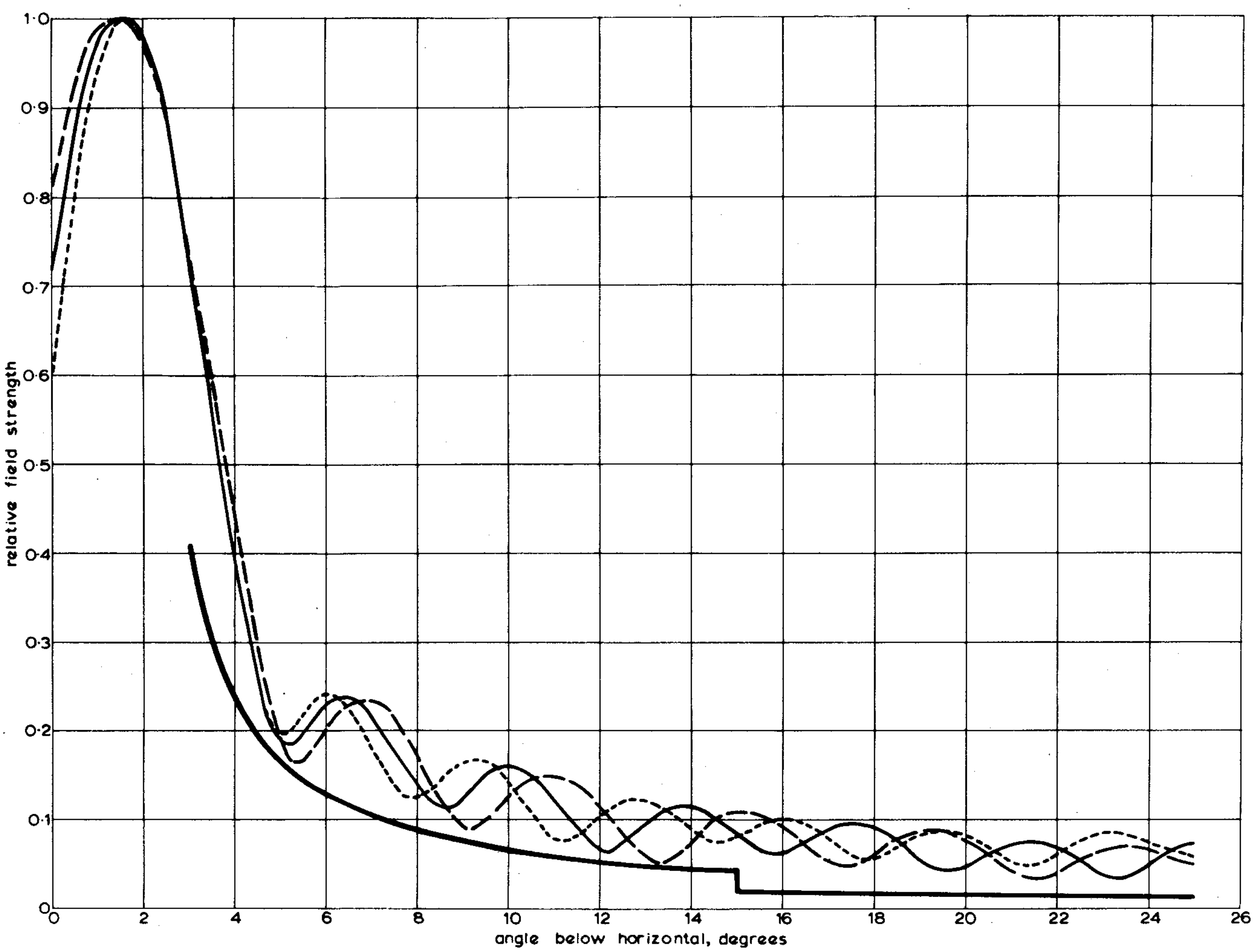

Fig. 11 - Theoretical vertical radiation pattern

— — *0·9 fo*   ---- *1·1 fo*

—— *fo, mid-band frequency*   ▬▬ *specified minimum field*

collinear dipoles are small but were taken into account on an array of four dipoles. At this stage the controls on the dipoles were dispensed with to avoid a multiplicity of controls on the full aerial and because small differences in the settings of these controls would make the desired vertical current distribution more difficult to achieve. A typical admittance characteristic of a single element mounted on the support channel is shown in Fig. 13.

Specimens of the glass-fibre cylinders did not become available until the first prototype aerial had been assembled. When this aerial was inserted in the cylinder with the dipole elements approximately on the cylinder axis the reflexion coefficient of each element was increased to 15% - 20% as a result of reflexions from the cylinder returning to the elements in phase. When, however, the elements were displaced from the cylinder axis, the match was improved and in the optimum position, with the dipoles quite close to the cylinder, a characteristic was obtained at least as good as that in free space.

Fig. 14 shows the reflexion coefficients of the half aerials as a function of frequency, when measured through cables having the same loss as the main feeders in a normal installation. The difference between the two curves arises from the form of the current distribution over the vertical length of the aerial; the lower half has the greater phase spread and therefore the greater self-cancellation of reflexions. This effect may be seen in Table VI where the reflexion coefficients of the separate half aerials and of the whole aerial relative to that of each element are calculated for the theoretical vertical current distribution, assuming zero loss in the distribution feeder.

The figures in Table VI may be used to deduce the permissible reflexion coefficients of the half aerials. The permissible reflexion coefficients for the whole aerial, measured at the input to the diplexer, is shown in Section 2.5 to be 2·1%. The corresponding figures for the half aerials, measured at the base of the main feeders, are given in Table VII.

TABLE V

Calculation of effective gain

	Channels 21-34		Channels 39-52		Channels 53-68	
		dB		dB		dB
Mean intrinsic gain		12·7		12·7		12·7
Deduct aerial losses:	dB		dB		dB	
Gapfilling	0·7		0·7		0·7	
Distribution feeder, UR67	1·7		1·6		1·5	
Distribution transformers	0·1	2·5	0·1	2·4	0·1	2·3
Mean net gain		10·2		10·3		10·4
Deduct other losses:						
Main feeder, HF 1 5/8 in.	0·9		1·0		1·1	
Feeder ground run HF 3/8 in.	0·2		0·2		0·2	
Diplexer	0·1	1·2	0·1	1·3	0·1	1·4
Mean effective gain		9·0		9·0		9·0
Aerial h.r.p. maximum/mean ratio		2·0		2·6		2·5
Maximum effective gain		11·0		11·6		11·5

TABLE VI

Relative reflexion coefficients of half aerials and the whole aerial

	$0·9\ f_0$	f_0	$1·1\ f_0$
Upper half aerial	$0·962\,\rho$	$0·954\,\rho$	$0·945\,\rho$
Lower half aerial	$0·697\,\rho$	$0·641\,\rho$	$0·589\,\rho$
Whole aerial	$0·180\,\rho$	$0·165\,\rho$	$0·260\,\rho$

f_0 = mid-band frequency
ρ = reflexion coefficient of a single element.

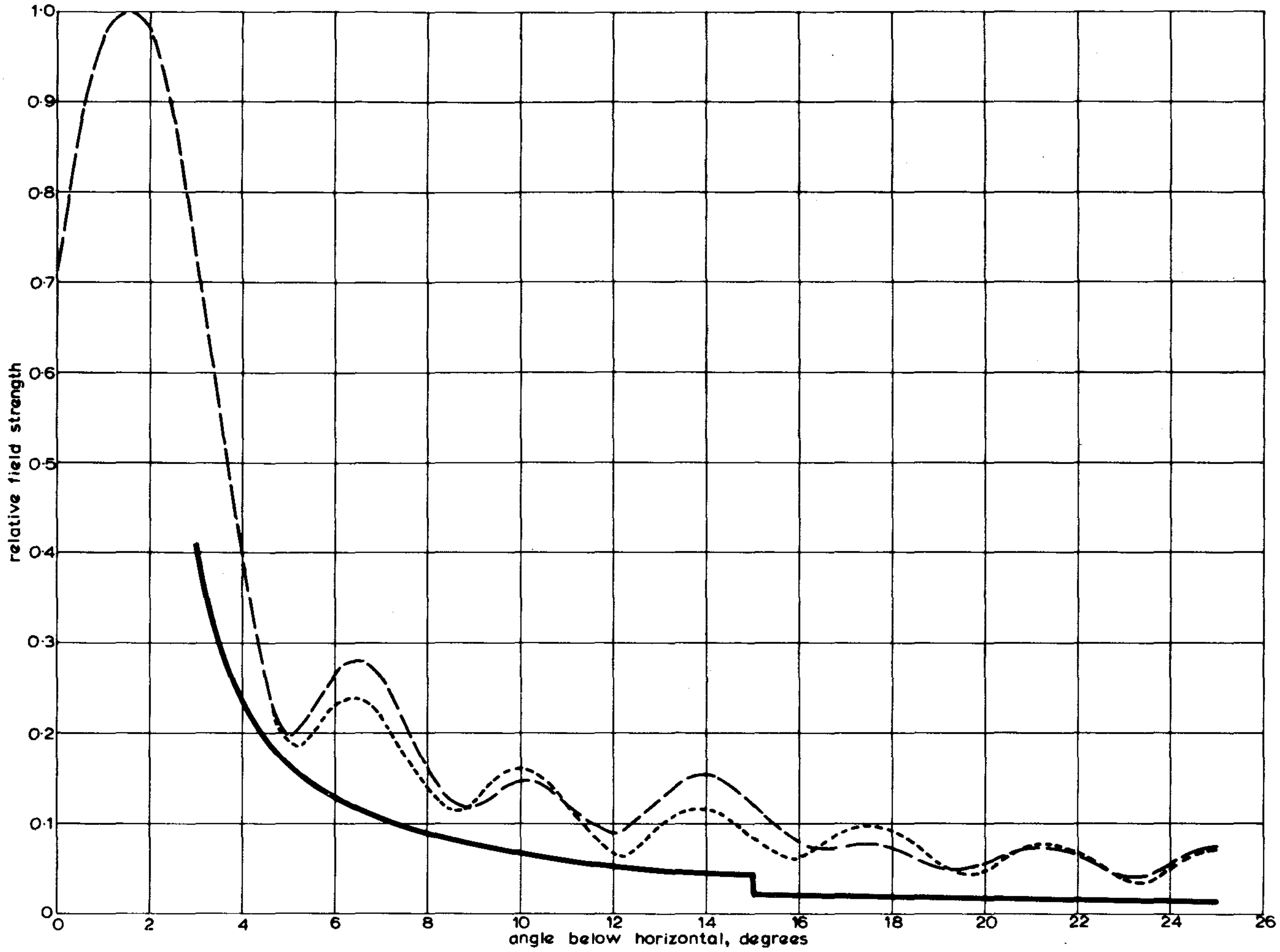

Fig. 12 - Measured vertical radiation pattern at mid-band frequency

—— —— *v.r.p. from measured currents*

- - - - - - - *v.r.p. from theoretical currents*

━━━━ *specified minimum field*

TABLE VII

Permissible reflexion coefficients of the half aerials

	0·9 *f*o	*f*o	1·1 *f*o
Upper half aerial	10·6%	12·1%	7·6%
Lower half aerial	8·1%	8·2%	4·8%

It may be seen that the measured reflexion coefficients of the prototype half-aerials, shown in Fig. 14, are within the limits given in Table VII.

A precise measurement of the reflexion coefficient of the whole aerial was difficult owing in part to the smallness of the reflexions and in part to reflexions from irregularities in the measuring cable (UR67) which is less uniform than the main feeder in a normal installation. For convenience, the length of the measuring cable was chosen to give the same loss as that of the main feeder in a normal installation. Fig. 15 shows the display on the Rohde and Schwarz 'Polyskop'; this shows the variation of voltage at the input to the measuring cable connecting the aerial to the instrument as the frequency is varied, so that adjacent maxima and minima correspond to the v.s.w.r. of the aerial. The greatest excursion within the nominal bandwidth of this model (614 MHz - 726 MHz) is approximately 0·35 dB, in the region 630 - 640 MHz, corresponding to a reflexion coefficient of about 2%.

4.5. Power Rating

At a Type 1 station, the power on each channel will be 1 kW peak vision plus 0·2 kW sound. The total mean power when the vision transmitter is radiating black level is 0·825 kW. When all four channels are in operation the mean power entering

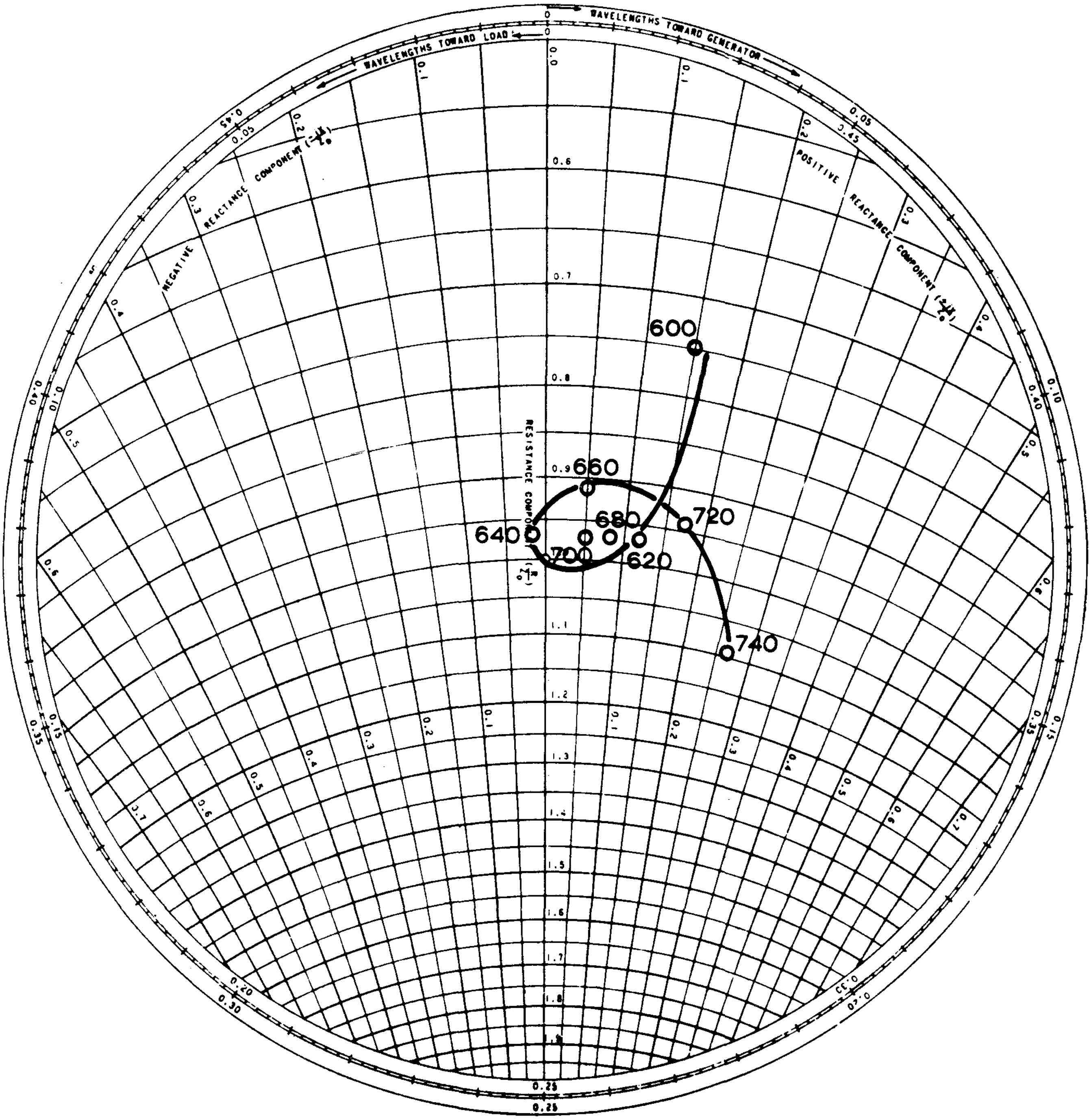

Fig. 13 - Admittance characteristic of single dipole model for Channels 39-52 (614 MHz - 726 MHz) measured without glass-fibre cylinder. The numbers on the curve refer to frequencies in MHz.

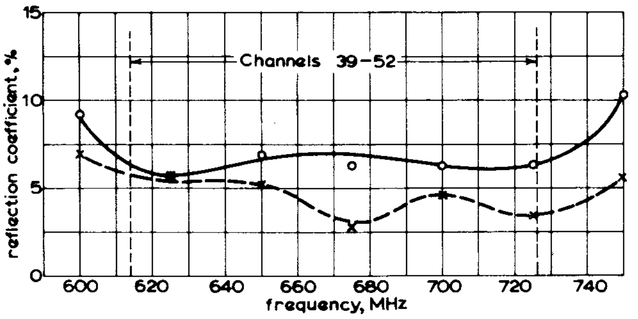

Fig. 14 - Reflexion coefficients of half-aerials in glass-fibre cylinder.

——o—— *Upper half aerial*
– – –X– – – *Lower half aerial*

each main feeder, allowing for loss in the combining units, will be 1·5 kW and that reaching the distribution transformers 1·2 kW; the mean power entering each distribution feeder will be 0·15 kW.

The power rating of the main feeders at the highest frequency channels is 4·5 kW* and that of the distribution feeders 0·27 kW*; the latter therefore dictate the power rating of the aerial. It would, however, be possible to increase the power rating be replacing the UR67 distribution feeders by the more expensive UR107, a cable having a PTFE dielectric and a much higher rating.

The above calculated ratings were verified on one half aerial. A range of powers was fed into the distribution transformer and the temperatures of the transformer and various parts of the cable forms were measured over a period of time. The results were generally satisfactory. However, with the highest input power used, 1·6 kW (corresponding to a 33% increase beyond normal operation), it was found that the temperature inside tightly bunched distribution cables could build up to an undesirable level. Accordingly, it was thought prudent to avoid such bunching on the production aerials; this was easily accomplished by fitting a cable tray across the support channel on the lower half aerial.

5. GENERAL ASSESSMENT OF THE AERIAL

5.1. Operational Experience

The first four production aerials were manufactured by the BBC Equipment Department and set to work by the BBC Transmitter Planning and Installation Department. Two of these, at Hertford and Tunbridge Wells, entered service without difficulty and have given satisfactory operation at low power over a period of nine months. Fig. 16 shows a general view of the installation at Tunbridge Wells.

5.2. Costs

Following the completion of development work on the prototype aerials, manufacturing drawings were sent to commercial firms with an invitation to tender for the supply of a number of aerials. Subsequently, contracts were placed by T.P.I.D. for

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* For an ambient temperature of 40°C.

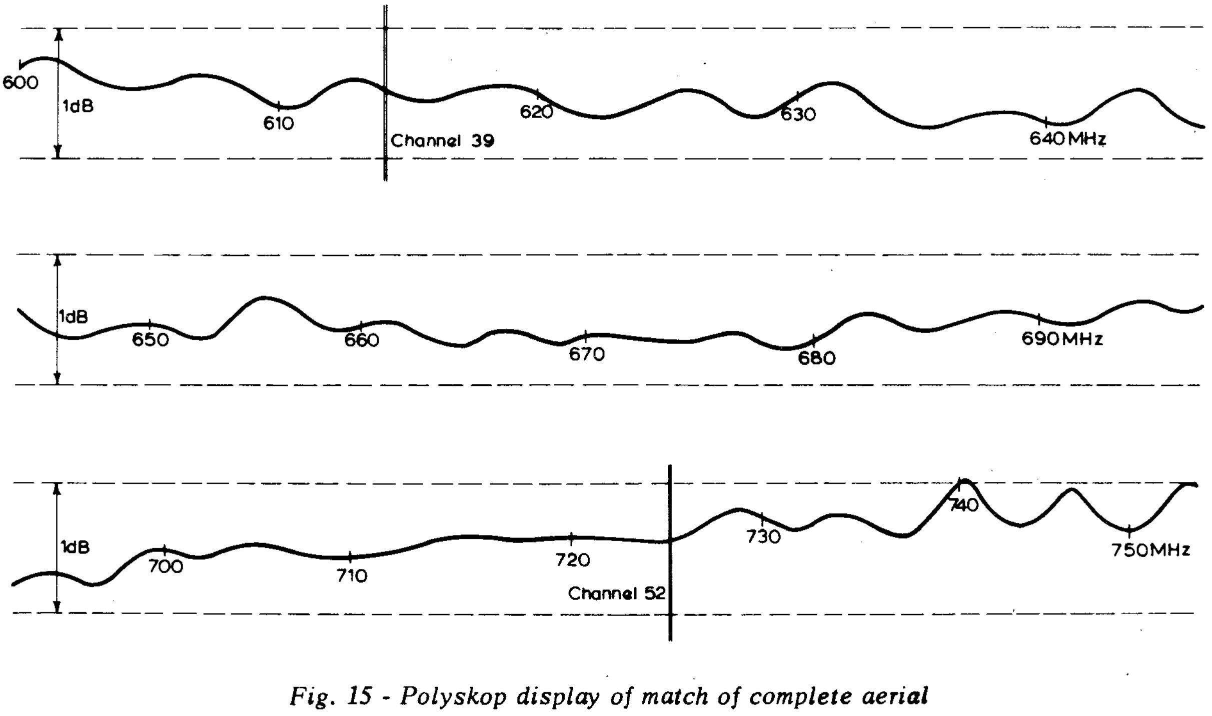

Fig. 15 - Polyskop display of match of complete aerial

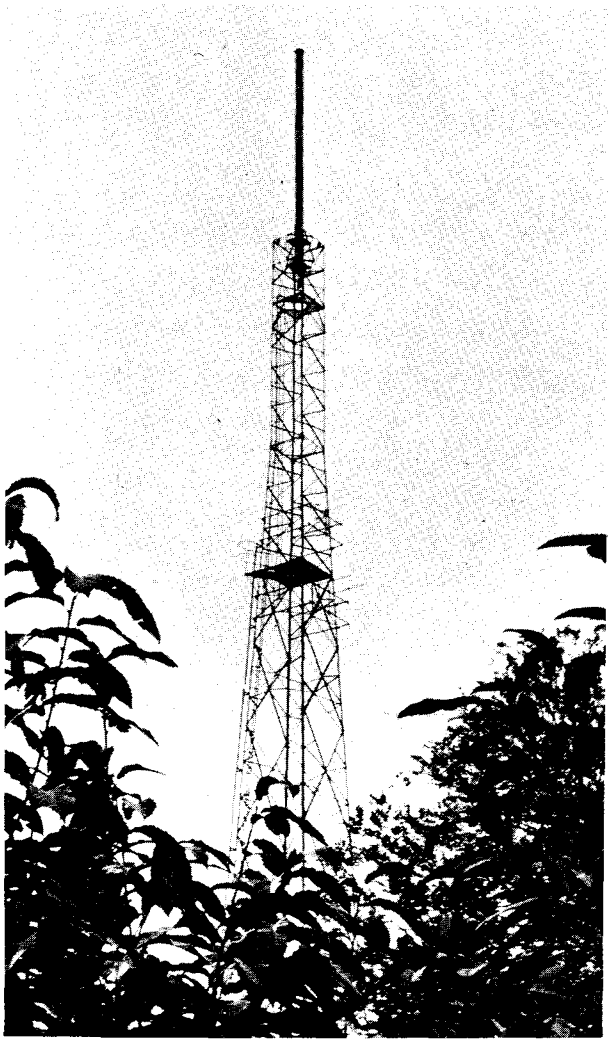

Fig. 16 - General view of the aerial installation at Tunbridge Wells

the supply of 15 aerials from each of two manufacturers. These orders showed a very substantial saving compared with the commercial offers based on arrangements of panels.

6. SPECIAL FORMS OF THE AERIAL

It was expected that the radiation characteristics of the standard 16λ cardioidal aerial would be unsuitable at a few stations and so some simple ways of varying these characteristics were investigated.

One possible requirement is for a more directional aerial either to conserve transmitter power or to reduce radiation in unwanted directions. This could be achieved by mounting a reflecting screen on the support channel, giving the horizontal radiation patterns shown in Fig. 17. At the time of writing, no application for this arrangement has emerged since, for difficult sites, an even more directional aerial is preferred.

Another possible requirement is for an elongated h.r.p., which was one of the forms considered at the outset (see Section 2.1). This may be achieved by placing a long conducting cylinder having a diameter of about 51 mm (2 in.), (e.g. a standard aluminium alloy scaffold pole) one quarter-wavelength in front of the dipoles. The h.r.p. of the arrangement is shown in Fig. 18. The reflexion coefficient of the dipoles is increased to about 15% but a satisfactory admittance characteristic can be restored by adjustments to the dipoles. No certain application for this arrangement has arisen as yet.

At some sites it is possible that a greater beam tilt and/or a greater beam-width in the vertical plane will be needed. The beam tilt of the standard 16λ aerial may be increased to 3·2° or 4·8° by modifying the distribution feeder arrangement. Alternatively the aerial may be reduced to 8λ with a beam tilt of 3·2°, giving the v.r.p. shown in Fig. 19. At least one application of the latter arrangement is planned.

7. CONCLUSIONS

The requirements for a simple but versatile aerial suitable for multi-channel operation have been met. The design described has proved suitable for the great majority of stations and is giving satisfactory service at the first two installations to be completed. Its use has already resulted in substantial savings in aerial costs.

8. ACKNOWLEDGMENTS

The general physical form of the aerial was arrived at in consultation with the BBC Transmitter Planning and Installation Department. The supply of the glass-fibre cylinders was arranged by the BBC Building Department.

9. REFERENCES

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2. Shaping the vertical radiation patterns of U.H.F. transmitting aerials by phase perturbation. Research Department Report No. E-121, Serial No. 1966/72.

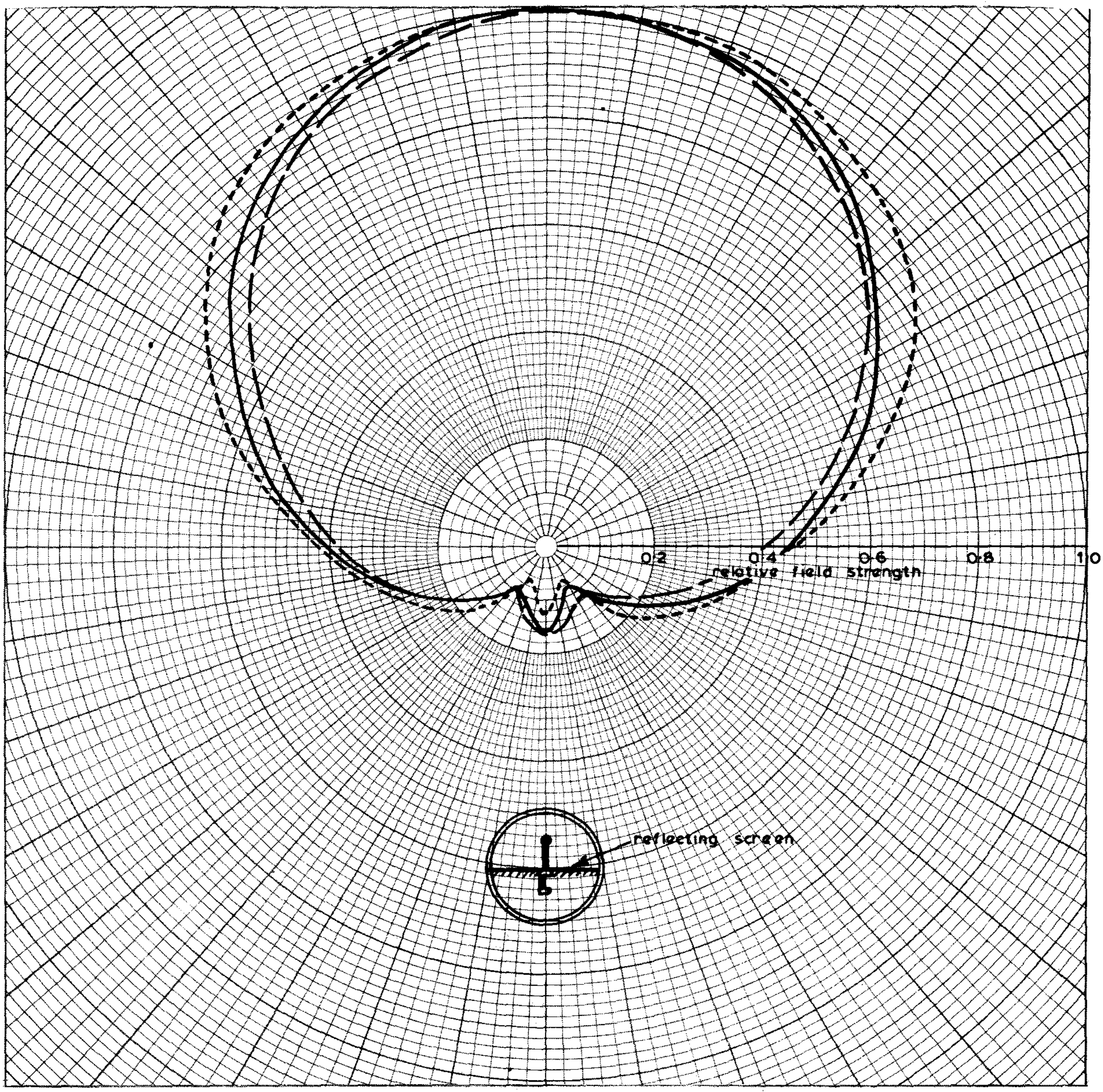

Fig. 17 - Arrangements for unidirectional h.r.p.
Measured h.r.p. at

— — 615 MHz
——— 670 MHz
– – – – 725 MHz

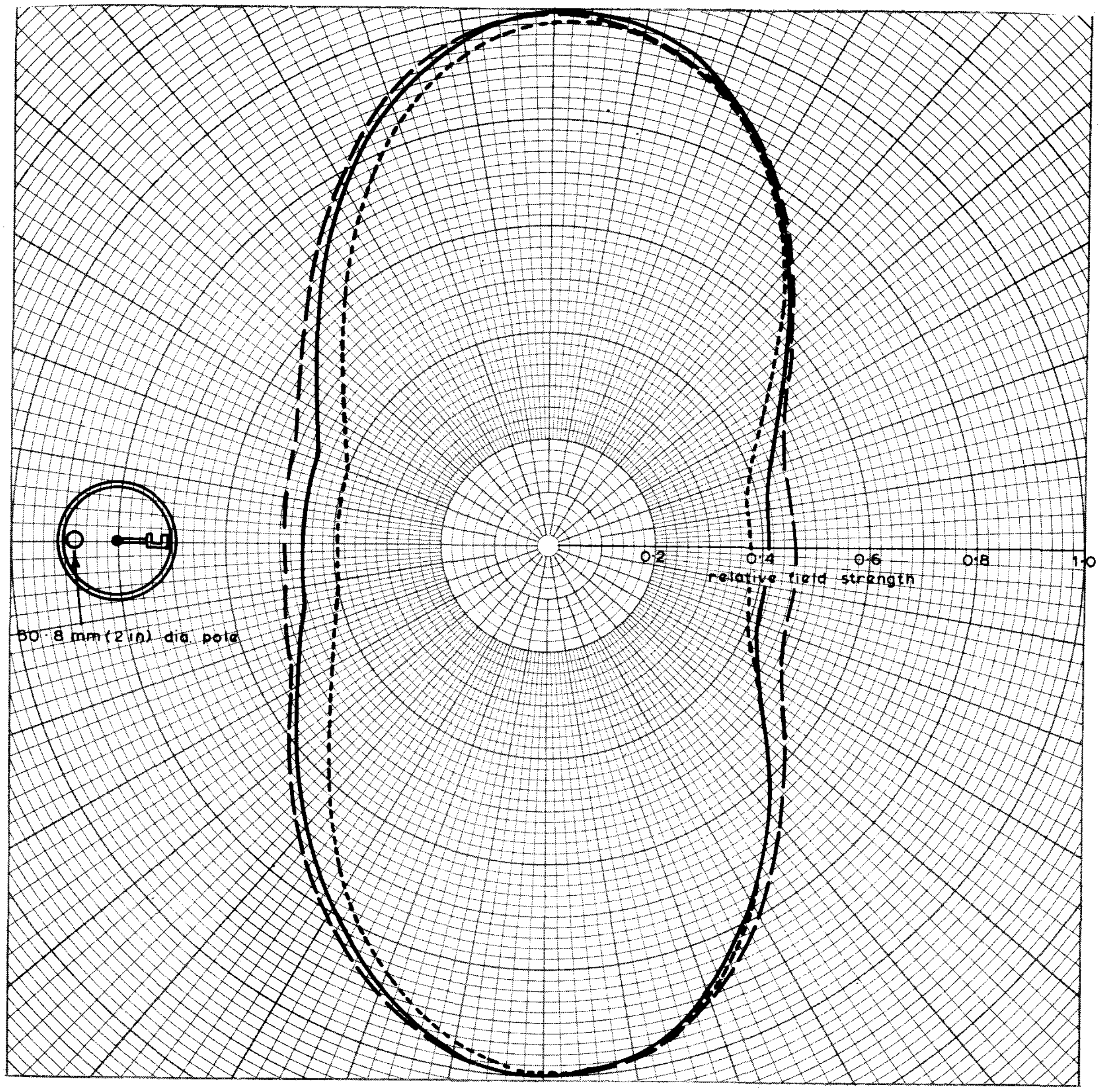

Fig. 18 - Arrangement for elongated h.r.p.
Measured h.r.p. at

— — 615 *MHz*
——— 670 *MHz*
- - - - - 725 *MHz*

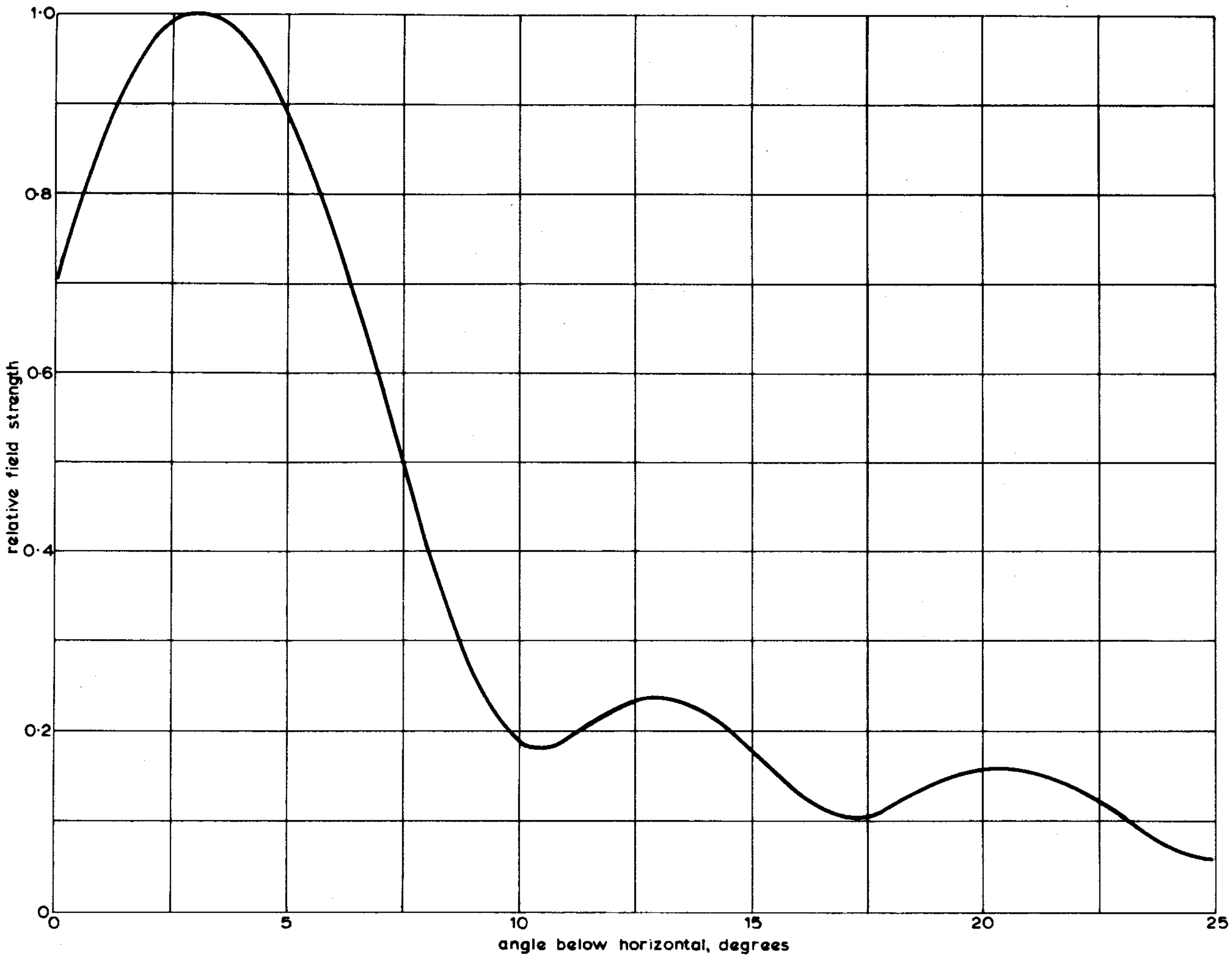

Fig. 19 - V.R.P. of 8λ transmitting aerial.

JMP

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